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May 28, 1993

BEFORE THE
FEDERAL COMMUNICATIONS COMMISSION
WASHINGTON, D.C. 20544

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FEDERAL COMMUNICATIONS COMMISSION
OFFICE OF THE SECRETARY

In the Matter of	)	
	)	
Replacement of Part 90 by Part 88 to Revise the Private Land Mobile Radio Services and Modify the Policies Governing Them	))))	**PR Docket No. 92-235**

COMMENTS OF DR. GREGORY M. STONE & ASSOCIATES

DR. GREGORY M. STONE & ASSOCIATES, is pleased to submit the attached Comments in response to the above captioned Notice of Proposed Rule Making.

Respectfully submitted,

28 MAY 1993

Dr. Gregory M. Stone, Principal Associate

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QUALIFICATION STATEMENT OF DR. GREGORY M. STONE

Dr. Gregory M. Stone is a consulting scientist and Principal of Dr. Gregory M. Stone & Associates of Alexandria, Virginia. Dr. Stone holds a Ph.D. in Electrical Engineering and has in excess of sixteen years experience in the area of wireless communications technology with concentration in both terrestrial and aeronautical systems. Dr. Stone is a member of the Institute of Electrical and Electronic Engineers and currently serve as Chairman of the Vehicular Technology Society's Propagation Committee. In addition, he is a member of the Radio Club of America and was awarded the status of Fellow in 1987 for his work performed in the areas of bandwidth and spectrally efficient wireless technologies. Over the past sixteen years Dr. Stone has served as a communications and technology consultant to a number of federal, state, local, and international public safety entities and to several large regional telephone companies cellular/mobile communications subsidiaries. In addition, Dr. Stone currently serves as a member of the Editorial Advisory Board for Mobile Radio Technology and as a Member of the Executive Committee of the IEEE International Carnahan Conference on Security Technology - Electronic Crime Countermeasures. Dr. Stone is the author of in excess of sixty (60) professional papers and reports dealing with technology related issues. Dr. Stone has served as an expert witness in the area of science and technology for a U.S. Government agency before the U.S. Congress.

The statements contained and opinions expressed in this filing are solely those of Dr. Gregory M. Stone and do not necessarily reflect those of any professional association, organization or client entity he is currently, or was previously, affiliated with.

SUMMARY COMMENTS

- We support the Commissions efforts to encourage spectrum efficiency through mandating bandwidth efficiency vis-a-vis narrow banding

- We are advancing for consideration several substantive technical objections to Commission proposed technical parameters, specifically limitations on effective radiated power, which will inhibit and frustrate the proliferation of bandwidth/spectrally efficient technologies

- We propose the Commission not adopt technical standards and parameters which effectively force interference limited system designs on private land mobile users, as its the case wit cellular and permit the frequency coordination process to determine the most efficacious frequency reuse distances considering a number of relevant parameters including but not limited to: electromagnetic wave propagation physics; and, the channel access, modulation and baseband multiplexing schemes employed.

- We propose standardizing on 6.25 KHz channel spacing, and permitting 100

% channel occupancy conditioned on compliance with certain stringent technical requirements

- We propose maintaining a very rigid time frame for the replacement of current systems and transition to narrowband, making an exception, in time frame only for Public Safety

- To provide for nearly unlimited future increases in spectrum efficiency, we propose the Commission initiate efforts to develop a comprehensive spectrum use strategy to accommodate the universal overlay of spectrum by communications systems employing Code Division Multiple Access (CDMA) techniques.

INTRODUCTION

New and innovative wireless techniques will continue to place increasing demands on the spectrum resource necessitating the long term implementation of both bandwidth and spectrally efficient technologies to improve the overall use efficiency of our radio frequency spectrum resource.

With the proliferation of digital signal processing, low cost application specific integrated circuits (ASIC) and monolithic microwave integrated circuitry, an opportunity exists to significantly advance the use efficiency of all wireless spectrum usages.

With spectrum refarming comes the "great" promise...the expansion of available discrete channels by between 300 and 500 % in the affected bands. However, is increased channel availability the real benefit of this major anticipated action? We think not.

We believe that the real promise of refarming is the stimulation of advanced digital communications technology that will revolutionize the personal communications industry as we know it today. Unfortunately, the proposed regulations contained in the NPRM will in effect stifle the proliferation and exploitation of the most viable bandwidth and spectrally efficient technologies through continuing to support antiquated and incorrect beliefs concerning the fundamental nature of spectrum efficiency, and by a failure to effectively consider the fundamental physics predicate to all communications.

However, if bandwidth and spectrally efficient technologies are stimulated and incentivized, one of the many benefits likely from the proliferation of advanced digital communications technology is the provision of fully imbedded signaling and integrated transmission of both voice and multi-media digital data.

The Commission today has a unique opportunity to adopt a highly proactive technology stimulative posture that will facilitate the development and deployment of virtual seamless information transport capabilities predicated upon wireless technologies. We encourage the Commission to proceed post haste.

SPECIFIC COMMENTS

SPECTRUM EFFICIENCY STANDARDS

We support the Commission's decision to use narrowband technology as the benchmark for use efficiency comparison. However, it is important to note that there is a definitive difference between **Spectrum Use Efficiency and Bandwidth and Spectral Efficiency**

The notion of spectrum use efficiency is complex however, one rather straight forward definition which we subscribe to and advance refers to the Erlangs per hertz per square kilometer area. With this metric, it is the maximal traffic capacity of a unit bandwidth over a given geographic area which defines the spectral use "density" and by extension its efficiency.

In the spectrum refarming NPRM under consideration, the commission makes reference to both spectrum-efficient technology and "narrowband" technology. It is important, in the discussion that follows, to recognize the differences between spectrum efficiency and bandwidth efficiency vis-a-vis narrowband technology.

In basic terms, bandwidth efficiency refers to the information capacity present in a given channel bandwidth based upon the work of Claude Shannon. This is often referred to as the *Shannon capacity* of a channel. Systems that employ modulation/channel coding techniques that operate at data rates significantly less than the Shannon channel capacity are not as bandwidth efficient as those that employ practices which approach the Shannon limit.

Contrasted, with bandwidth efficiency, *spectrum efficiency* refers to a mission or use, and is much more than merely considering the bandwidth *quantity*. It is critical though, to realize that unless one has efficient utilization of channel bandwidth, ultimate spectral efficiency can never be accomplished. In this light, spectrum efficiency also must consider such parameters as trunking efficiency, frequency reuse, and most importantly, the mission or intended use of the spectrum.

For example, the scenario could be devised where frequencies in the 160-meter band (AM broadcast) were utilized for radio paging in an urban area. Even if bandwidth efficient technology is employed, using the 160-meter band for urban paging is not spectrally efficient because the 160-meter wavelength is not suitable where building penetration is an important criterion. Therefore, spectrum efficiency is multi-dimensional. In narrowband frequency division multiple access (FDMA) and in those hybrid systems employing FDMA as part of the complex multiplexing scheme, bandwidth efficiency a necessary constituent part of spectrum efficiency. Thus in the particular case of FDMA, spectrum efficiency may be viewed as an integration of bandwidth efficient technology utilizing the *ideal* wavelength for transmission, along with the proper application of such practices as optimal channel coding and power densities, controlled interference frequency reuse, and trunking. Thus, when taken as a composite whole, an FDMA based communications system employing the optimal wavelength, bandwidth efficient technology in addition to trunking and either non-interference based reuse or alternatively controlled interference frequency reuse (where reuse is adaptive and dependent upon the bandwidth efficient scheme employed) may then be viewed as a "spectrally efficient" system.

In FDMA systems, it is relatively straightforward to develop a quantitative means to assess "bandwidth efficiency" where the metric is channel capacity per unit bandwidth where channel capacity is expressed in terms of bits per second (b/s) per Hertz (/Hz) unit bandwidth. Thus, if one were to take an occupied bandwidth of say 4.0 KHz, employ m-ary modulation with a channel information rate of 9.6 kb/s the bandwidth efficiency of such a use would be 2.4 b/s/Hz. If the channel information rate were increased to 15.2 kb/s, maintaining constant occupied bandwidth the bandwidth efficiency increases to 3.8 b/s/Hz.

With TDMA systems, the "bandwidth efficiency" must be normalized over the entire occupied bandwidth. Why, because in TDMA systems, the entire authorized bandwidth is used with information capacity multiplexed over the n time slots, and there information rate capacities, provided in the specific TDMA implementation. As an example, if a "narrowband" TDMA scheme is proposed that has an occupied bandwidth of 24 KHz, has a gross information rate in the 30 KHz channel of 48 kb/s and employs 4 time slots, each time slot could be allocated an information transfer rate of 12 kb/s. In this scenario, the bandwidth efficiency of the TDMA system would be based upon the gross information transfer rate normalized over the 30 KHz occupied bandwidth resulting in a bandwidth efficiency of 2.0 b/s/Hz. Furthermore, depending upon the characteristics of the traffic carried, with a team size of four (4) and additional trunking efficiency may be accrued that under some circumstances may permit improved access to the spectrum resource.

The most complicated access methodology is CDMA or code division multiple access.

This is one reason why we assert that spectrum use efficiency is so complex. A more detailed definition of access modalities is presented in Appendix-A.

TECHNICAL AND OPERATIONAL RULE CHANGES:

Reference Narrowband Migration/Transition Period

We support the Commissions strategy to require the reduction in modulation index to effect a channel occupancy of 10 KHz to create spectral "gaps" that may be used to permit the insertion of narrowband technology.

It is our opinion that based upon current equipment fielded, relatively simple modifications are required to "narrow band" detection systems so that the system noise performance is maintained.

We also propose that a uniform channelization be specified for ALL private radio services not limited to those below 512 MHz but including all current 800-900 MHz and future "L" band and above usages.

However, we strongly suggest that in the Public Safety services, public safety entities who operate encrypted equipment employing F3E or F9E emissions be permitted to continue said operations for some unspecified, indefinite period of time. Most encrypted public safety systems especially those interoperable systems which comply with the Office of National Drug control Policy's National Telecommunications Master Plan for Drug Enforcement, employ digital emissions that are NOT amenable to broad scope narrow banding. These NTMPDE drug enforcement interoperable systems are encrypted with the Data Encryption Standard (DES) cryptographic algorithm operating in the single bit cipher feedback mode (CFB) and employ continuously variable slope delta modulation (CVSD) at a bit rate of 12.0 kb/s and is transported via binary frequency shift keying (FSK). While this technology is old, it is currently and is anticipated to remain the mandated STANDARD for drug law enforcement interoperable communications. Various estimates place the public safety investment in this technology in the area of 900 million dollars. To preserve the operational integrity of these systems, their instantaneous frequency deviation is set to 4.0 KHz. with an equivalent modulating frequency of 6.0 KHz (corresponding to a transmitted data rate of 12.0 kb/s via binary FSK) bandwidth occupancy is approximately equivalent to 5.0 KHz deviated analog voice and necessitates the use of a 25/30 KHz channel. It is NOT possible to reduce the instantaneous frequency deviation of these 12.0 kb/s encrypted digital voice with out destroying the range and operational performance of these systems. In addition, any tampering with the 12.0 kb/s operational parameters will render those systems in place with state and local law enforcement non-interoperable with federal agencies who almost exclusively employ 12.0 kb/systems for all operational traffic not limited to drug law enforcement.

We propose the Commission grandfather the Pubic Safety use of 12.0 kb/s encrypted digital voice systems, until such time as a new national standard is adopted and subject to state and local agency funding/budgetary replacement cycles.

We additionally propose that the Commission mandate that all next generation digital public safety equipment fielded must be backward compatible and interoperable with existing pubic safety digital equipment that complies with the ONDCP/NTMPDE drug law enforcement interoperability standard.

Reference 88.413 & 88.425 Bandwidth Limitations and Emission Masks

We take exception to the Commissions proposal to limit authorized bandwidth to approximately 80% of the channel spacing or authorized bandwidth. Given the advancements in communications technology and the need to promote substantive increases in spectrum use efficiency vis-a-vis the proliferation of bandwidth efficient technologies, it is in the public interest to permit full utilization of available channel bandwidth.

Current technologies will allow for the suppression of out of band intermodulation products by at least 75 dB through the use of linearized amplifiers employing DSP based feed forward control. In addition, current DSP based filtering technology will permit the practical implementation of "brick wall" rectangular/Nyquist filters.

In addition, with the imposition of very stringent, but practically realizable, frequency control and stability requirements on subscriber equipment the need for "guard band" allocation is unnecessary. For example, automatic frequency control based upon sample and hold AFC techniques employing traditional high stability or atomic reference standards could provide subscriber sets with frequency stabilities comparable to that of fixed equipment that is otherwise unattainable.

However, for those systems whose operational requirements do not dictate the use of the full authorized bandwidth, the Commission's proposal for 80%, with the proposed technical parameters concerning emission mask and frequency stability could remain.

Thus the promulgation of FLEXIBLE standards permitting full channel bandwidth occupancy under certain specific conditions is not only highly desirable, it is practicable and in our judgment essential to promote technology advancement.

The bottom line is that the technical parameters adopted MUST promote the implementation of these bandwidth/spectrally efficient technologies.

We therefore propose the Commission permit authorize bandwidth, defined as containing those frequencies upon which 99% of the radiated power appears, extended to include any discrete frequency upon which the power is at least 0.25 % of the total radiated power, to be equivalent to the "channel spacing" or "authorized bandwidth if the frequency stability of the system is kept to that specified for the fixed station infrastructure. Attenuation at the edge of the authorized channel where the authorized channel and authorized bandwidth are equivalent should be specified at 50 dB down at the edge of the authorized bandwidth of the adjacent channel. Thus if an adjacent channel 6.25 KHz channel requested an authorized bandwidth of 5.0 KHz have to be 50 dB down .625 KHz removed from the 6.25 KHz authorized bandwidth channel edge. Likewise, if adjacent 6.25 KHz channels both employed 6.25 KHz authorized/occupied bandwidths, at the channel edge signals must be 50 dB down necessitating the use of rectangular "brick wall" filtering technology and very low distortion amplifier techniques.

Reference 88.429 Effective Radiated Power and Antenna Height Above Average Terrain

With this Spectrum Refarming NPRM the Commission is proposing dramatic reductions in permissible effective radiated power levels. This approach, in our judgment is ill advised at best because the arbitrary limitation of power whilst concomitantly requirement and ostensibly promoting bandwidth efficiency is technically unsound. As will be discussed below, the Shannon channel capacity theorem is clear in this regard, improved bandwidth efficiency DEMANDS increased power. Likewise Nyquist addressed the issue of symbol detection and hoe to avoid inter symbol interference.

In all of the excitement surrounding the wireless digital revolution, often one looses sight of the basic principles that dictate what and how well techniques will perform in the physical world. Whilst adequate space is not available to exhaustively address the Nyquist theorem or the Shannon Channel Capacity Theorem, certain principles, fundamental to our discussions here, must be restated.

Nyquist stated that the theoretical minimum bandwidth needed to transmit x symbols per second without inter-symbol-interference (ISI) is $x/2$ Hz, representing a basic and fundamental constraint. With the advent of digital signal processor based "brick wall " filters, one half symbol rate bandwidth occupancy is becoming more practicable where in the past the rule was that a double sided Nyquist bandwidth of x Hz was resulting in 1 symbol per second per Hertz bandwidth (1S/s/Hz). Even with that constraint, dramatic bandwidth efficiencies may be obtained as discussed below, but at a cost...additional power.

In the digital process, efficient digital transmission may occur if the source data and channel employ proper coding techniques. In this context coding refers to the number of bits that may be "coded" onto one symbol as defined by Nyquist. This is the basic fundamental behind bandwidth efficient modulation. A more detailed discussion on this is presented in Appendix-C. Assuming proper coding is employed, a channel of W Hz bandwidth has a capacity C, for various RF carrier-to-noise ratios (CNR) which may be determined via the Shannon Channel Capacity theorem which is contained in the following expression:

$$C = W \log_2 (1+\text{CNR})$$

From this equation, assuming carrier-to-noise ratios of 1 dB through 18 dB correspond to the maximal bandwidth efficiency values with perfect coding are presented in Table-1 that follows:

TABLE-1

Bandwidth Efficiency Value	Required Carrier-to-Noise Ratio (CNR)
2.0 b/s/Hz	5.0 dB (3.15)
3.0 b/s/Hz	8.0 dB (6.3)
4.0 b/s/Hz	12 dB (15.8)
5.0 b/s/Hz	15 dB (31.6)
6.0 b/s/Hz	18 dB (63)

Note: These values reflect rounding.

A channel with an occupied bandwidth (consistent with proposed authorized bandwidths of 4.0 and 5.0 KHz respectively) 4.0 KHz wide, with an RF CNR of 25 (14 dB which is very typical in land mobile radio) would have a theoretical data rate capacity of 18.8 kb/s, which equates to a bandwidth efficiency of 4.7 b/s/Hz. At an occupied bandwidth of 5.0 KHz channel information rate increases to 23.5 kb/s. Unfortunately, in practice, it is not possible to obtain the full theoretical Shannon channel capacity. But still, it is possible to employ channel coding, and to fully exploit advances in DSP based filtering that permits highly efficient use of bandwidth which may closely approach the capacity limit defined by Shannon.

What is important to note is the relationship between information capacity, bandwidth and power. The Shannon theorem indicates that the easiest means to increase channel information capacity is by increasing bandwidth W, and the most difficult means to increase channel information rate is by increasing power. Power increase is at a disadvantage as channel capacity only increases with the logarithm of power.

Thus, one is faced with two and only two fundamental choices: If one desires to limit power one must increase bandwidth; or, if one desires to limit bandwidth one must provide for increased power.

With this in perspective, keep in mind the proposals currently being advanced by the Commission and other regulatory bodies to restrict bandwidth and to limit power, ostensibly to promote increased bandwidth and spectral efficiency.

Of course, binary signaling such as 2-PSK, 2-FSK, or 2-ASK, is limited to an information bit rate of 1.0 b/s/c/s under ideal conditions. This is due to the fact that the bit rate and the baud symbol rate in binary systems are equivalent; and in order to avoid inter-symbol interference, as promulgated by Nyquist, two symbols (0,1) per given unit time is the maximum transmission rate with binary techniques. Because of this, some type of high-level (m-ary) channel coding is needed to increase the information transfer rate per symbol transmitted. Thus, with m-ary signaling, increased information rates are possible while conserving bandwidth, at the expense of carrier-to-noise ratios. Because land mobile is not a "power limited" service, it is prudent to trade power efficiency for efficient bandwidth and spectral utilization.

The key to effective exploitation of bandwidth efficiency, assuming that adequate power is permitted, is though the use of multi-level (m-ary) modulation/coding in which many information bits are encoded into each symbol transmitted. Thus, while in binary systems the information bit rate is equivalent to the transmitted baud rate, with m-ary coding, the information rate conveyed is higher than the symbol baud rate. We believe that today, in 1993, the most promising m-ary technique is that of Quadrature Amplitude Modulation (QAM). With these techniques, bit rate capacity is determined by the number of phase and amplitude levels. It is interesting to note that much publicity recently has been directed at pi/4 QPSK modulation. In reality, such is a form of QAM and as such represents the entry level into the bandwidth efficient modulation domain. The bandwidth efficiency in terms of bits per second per hertz bandwidth (b/s/Hz) is a function of the coding level employed. In this discussion we are assuming that the coding and information transfer rate of the symbols transmitted do not exceed the Nyquist rate. Thus with 4-QAM (four level QAM) the theoretical efficiency is 2 b/s/Hz. Thus, assuming perfect filtering a 9.6 kb/s data rate signal could be transported over a 4.8 KHz occupied channel bandwidth. This means that under the current FCC proposal., the 9.6 kb/s information rate signal could fit within a 6.25 KHz channel but with an occupancy of 4.8 KHz it would not fit within a 4.0 KHz occupied bandwidth. One solution to the dilemma is to make authorized channel bandwidth and occupied bandwidth values the same whilst still mandating acceptable emission masks. These relationships are presented in Table-2:

TABLE-2

Modulation	Theoretical B/W Efficiency	Attainable B/W Efficiency
4-QAM	2 b/s/Hz	2 b/s/Hz
16-QAM	4 b/s/Hz	3.8-4 b/s/Hz
64 QAM	6 b/s/Hz	5.7-6 b/s/Hz

Thus, referring to Table-2, 16 QAM would have a maximum theoretical bandwidth efficiency of 4.0 b/s/Hz. The 64 QAM mode, then would have an information capacity of 6.0 b/s/Hz. In the Commission's proposed occupied bandwidth of 4.0 or 5.0 KHz, effective data rates of at least 22.8 kb/s are achievable with 64 QAM.

For realizable QAM systems, the relationship between bandwidth efficiency and power requirements in terms of carrier-to-noise ratio in a double sided Nyquist bandwidth that equals the transmit symbol rate, for a 10^{-6} bit-error-rate (BER) are presented in Table-3:

TABLE-3

QAM Bandwidth Efficiency	Carrier-to-Noise (CNR) Ratio Required
4-QAM @ 2 b/s/Hz	14 dB
16-QAM @ 4 b/s/Hz	20 dB
64-QAM @ 6 b/s/Hz	26 dB

Thus, from Table-3 it may be seen that while the power efficiency of binary or even 4-

ary signaling is fairly good, very high bandwidth efficiencies pay the price of significant increases in power. In this example, if one were to initially employ 4-QAM and migrate to 16-QAM, to effect the same error performance, a 6.0 dB (factor of four) increase in power is required.

Compare the results of Table-3 with the Shannon theoretical limit presented in Table-1, and it becomes obvious that significant improvement in coding efficiency are needed to operate at or near the Shannon limit. For example, with 16-QAM, at a bandwidth efficiency of 4 b/s/Hz the required CNR is 20 dB, for systems operating at the Shannon limit, 4 b/s/Hz the Theorem states that a CNR of only 12 dB is required. In practice therefore, with advanced techniques we still are many dB's (in the case of 4 b/s/Hz a minimum of 6 dB) removed form the theoretical limit. Remember too that the values in Table-1 are for "error free" transmission whilst the practical values in Table-3 are for a BER of 10^{-6} , which while respectable, is certainly not error free.

Detractors of narrowband and bandwidth efficient technologies represent that a mobile communications channel is characterized by phase and amplitude distortions of such a degree that they make the use of "high" level very bandwidth efficient modulations , such as 16 QAM or better, impossible.

Such positions are indefensible and ignore the tremendous advancements in phase and amplitude perturbation correction made over the last twenty years, that permits a complex Rayleigh/log normal channel to become a first order time invariant Gaussian channel. Such channel linearization techniques as Feed Forward Signal Regeneration (FFSR) and Transparent Tone In-Band (TTIB), developed in the early 1980's by Dr. Joseph McGeehan and Dr. Andrew Bateman, are the best examples today of such practices and are proven in their effectiveness.

In McGeehan's 1980's FFSR/TTIB research, using 16 QAM modulation very low error (10^{-6} BER) transmission at approximately 13 kb/s in a 3.4 KHz occupied bandwidth, was demonstrated at 400 MHz under Rayleigh faded conditions approximating a vehicle velocity of approximately 100 km/h. McGeehan obtained this performance level without the use of any error detection and correction (EDAC) and simply relied upon the FFSR/TTIB channel linearization techniques to provide a solid time invariant channel.

The Commission's assumptions regarding desired to undesired ratios are therefore technically indefensible. The desired to undesired ratio is a function of the bandwidth efficient modulation technique employed and such parameters as diversity improvement and channel linearization/normalization technique employed and the detection technique used.

Manufacturers must provide quantitative data addressing such parameters to assist system designers establish the needed system power budgets including antenna heights and effective radiated power levels. Likewise, the requirement to mandate manufactures to provide quantitative data concerning their equipment's performance will enable frequency coordinators to establish suitable BANDWIDTH EFFICIENT TECHNOLOGY SPECIFIC service and protection contours.

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This posture will promote the deployment of highly efficient technologies.

Reference Promotion of Interoperability

We propose that the Commission fully endorse and codify the Project 25 work of the Associated Public Safety Communications Officer (APCO) organization as it affects pubic safety communications. In this regard, the Commission should respect a 12.5 KHz migration strategy evolving to 6.25 KHz as proposed by APCO.

However, we suggest the Commission mandate that all APCO Project 25 compliant equipment sold be backward compatible and interoperable with the ONDCP/NTMPDE mandated 12.0 kb/s DES encrypted standard. The Commission's leadership in this regard will lend invaluable support to APCO and its Project 25 efforts while assuring that the existing hundreds of millions of dollars investment in drug law enforcement should be encouraged to the greatest extent feasible, with a minimum of governmental restraints and regulation.

However, we believe the proposed action by the Commission does not go far enough to encourage the development and application of wideband technology.

We propose that ALL services currently licensable under the existing Part 90 be afforded the option to utilize spread spectrum or other broad band technologies.

The Commission should take affirmative measures to encourage the proliferation of technology relevant to public communications privacy and security through a relaxed regulatory posture, specifically as it applies to spread spectrum and other broadband emissions employing covert waveforms.

Thus, the general authorization, on a non-interfering basis, of wideband and spread spectrum emissions employing covert waveforms to all licensee categories will be an important step.

Licensees, and the public in general, should have equal and ready access to technologies that may enhance their competitive posture through affording secure and jam resistant communications. In addition the use of spread spectrum and other suitable wideband techniques will afford heretofore unrealizable gains in spectrum use efficiency though permitting the universal overlay of vast blocks of spectrum.

In the case of proposed part 88 technical standards pertaining to spread spectrum emissions, we suggest hat effective radiated power for frequency hopped systems be linked to their hop rate, dwell time, number and distribution of hopping frequencies. With direct sequence spread spectrum and other wideband systems employing covert waveform technologies, power must be expressed in terms of a spectral power density normalized over a given occupied bandwidth.

For frequency hopped systems, we suggest mandating the hoping sequence follow a rectangular distribution in a pseudo-random fashion and mandate maximum channel dwell time of 10 m/s. Effective radiated power levels should be tied to both dwell time and the number of discrete hopping frequencies where frequencies are separated by at least 30 KHz. A maximum instantaneous effective radiated power of 15 Watts appears reasonable at a dwell of 20 m/s over 10 hopping frequencies. Effective radiated power levels of 150 Watts should be permitted in systems that employ a dwell time of 1 m/s or less and hop over 100 or more discrete frequencies. These values will provide for impulses that are generally outside of the integration times of most detection systems.

In the case of direct sequence spread spectrum, 10.0 mW/KHz or 1.0 x 10 exp. -5 W/Hz is a reasonable value for general overlay over all Part 88 spectrum. Thus specifying a Spectral Power Density of 1.0x10 exp. -5 W/Hz a DSSS station operating at an effective radiated power level of 100 Watts would require a spreading function of 1.0 x 10 exp. 07 Hz or 10 MHz bandwidth.

APPENDIX - A

CHANNEL ACCESS MODALITIES

There basic types of channel access may be employed in addition to hybrids thereof these are:

- Frequency Division Multiple Access or FDMA
- Time Division Multiple Access or TDMA
- Code Division Multiple Access or CDMA

FDMA: With FDMA the available bandwidth is divided into n number of smaller bandwidth segments. Thus, a 1 MHz block of spectrum might be segmented into 160 channel each with a 6.25 KHz channel bandwidth. Traditionally, FDMA has been employed for land mobile, aeronautical mobile and maritime mobile applications. Existing channelization of 5, 12.5, 20, 25 or 30 KHz is predicated upon FDMA channel access.

With TDMA, an entire block of spectrum, i.e. 1.0 MHz is segmented into non-overlapping time slots each of a given duration. For satellite communications, video and high bandwidth usages are typically conveyed via FDMA means with voice and data traffic handled via TDMA whether direct or via multilevel TDMA/FDMA multiplexing techniques.

CDMA like TDMA makes use of a "block" of spectrum. However the multiple access addressing of CDMA allows multiple CDMA systems to use the same spectrum bandwidth i.e, 1 MHz, at he same "time" through the employment of orthogonal code transformation. CDMA usage is, for the most part, limited to specialized applications however there are serious plans to employ CDMA in future generation advanced digital cellular and other public correspondence systems. One means of effecting CDMA is through direct sequence spread spectrum means. If the pseudo-random pseudo-noise (RN) coding sequence with DSSS is chosen properly, a highly covert waveform may result that may be harmlessly overlaid over existing narrower band services without degradation. Additionally, PN-DSSS may afford some degree of transmission security through its low probability of detection (LPD) low probability of intercept (LPI) characteristics.

It is important to note that the multiple access mode only defines the ADDRESS technique and does not characterize the communication system completely. To fully characterize a communications link, the type of modulations and the multiplex technique of the baseband information must be specified and defined in addition to the multiple access technique used. For example, FDMA/FM/FDM states that frequency division multiple access (FDMA) is used and that each discrete carrier is frequency modulated (FM) and that the base band signals are frequency division multiplexed (FDM).

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In the past, the Commission took the position that substantive improvements in spectrum use efficiency could be obtained thorough "narrow banding" of the mobile radio spectrum. Thus, former channels with 60 KHz authorized bandwidth employing 15 KHz frequency deviation were "narrow banded" to 30 KHz channels with instantaneous frequency deviation limited to 5 KHz.

Today, we see advanced a proposal to accrue further improvements in spectrum use efficiency by additional FDMA narrow banding, while ostensibly permitting other access modalities such as TDMA or CDMA if such alternative access modalities accrue a net use efficiency comparable to the baseline FDMA channelization proposed. Furthermore, both TDMA and CDMA require network synchronization. In

APPENDIX -B

SYSTEMS ENGINEERING CONSIDERATIONS

The digital and analog worlds represent distinctly different considerations relative to the practical implementation and use of technologies. In analog practice, issues such as phase distortion and frequency offset are present but in many instances may be ignored. However, in the digital world, preserving the integrity of system timing, phase and amplitude coherency is often an a absolute requirement.

For example, in analog systems we typical engineer from a system power budget perspective considering gains such as effective radiated power and effective detection system sensitivity; , and losses such as mean propagation loss and the appropriate correction factors. System reliability is defined in terms of maintaining some specified signal level, equivalent to some quality metric such as 20 dB S.I.N.A.D., for some given reliability such as 99% of the time over some prescribed area of coverage i.e. 99% of the area with in a 20 mile coverage contour.

In these instances analog systems make use of a fat (non-frequency selective) fade margin where-by some power budget margin, i.e. 30dB, above the signal mean will provide the desired reliability a the desired signal quality metric. However, the use of a "flat" fade margin in digital wireless systems is a meaningless concept when considering the bit-error-rate behavior of a digital wireless system. This is because the frequency-selective behavior of multipath attenuation results in an error ratio greater than that which would be caused by nonselective attenuation of the same mean signal amplitude.

Under this scheme the proposed emission masks will provide 40 dB of attenuation at the edge of the authorized channel (not bandwidth), 50 dB of attenuation at the edge of the authorized bandwidth of the adjacent channel, and 65 dB of attenuation thereafter.

Now of course, the proposed narrower FDMA channels do not mandate the use of digital technologies. And , depending upon how the power level issue is resolved, analog single side band may prove to be the only really viable technology. In fact, single sideband in the form of in the form of amplitude companded single sideband (ACSSB), a fifty year old technique, is a likely and potentially aggressive candidate that may provide for cost effective narrowband communications in these narrower channels. ACSSB (actually amplitude companded double sideband) was initially techniques as McGeehan's Transparent tone In-Band (TTIB) with Feed Forward Signal Regeneration (FFSR). The result being a very bandwidth efficient digital implementation. Being a direct liner frequency conversion bandwidth occupancy at radio frequency that is proportional to the baseband bandwidth, which has been frequency translated. Of course RF. power amplifiers are analog devices but if the innate structure of the information conveyed is digital the transmission may be viewed as such. In this context, some prefer to view a digital modulator and RF. transmitter as a RF. modem.

To accommodate emerging multi-media applications involving digital voice, digital text and digital imagery/video, these bandwidth efficient digital implementations are necessary to exploit the very limited occupied bandwidths proposed with either 5 or 6.25 KHz channels. Such multi-media applications could easily necessitate the use of 64-QAM which could provide for information transfer rates of 24-30 kb/s in the FCC narrowband channels.

But as compared to today's digital practice how much of an improvement in bandwidth efficient technology is necessary? We believe quite a lot. Consider for example, if the APCO Project 25's proposed channel format becomes a final standard, a gross channel rate of 9.6 kb/s is required. Thus, in terms of bandwidth efficiency (assuming a 9.6 kb/s gross channel data rate), at a 5.0 KHz occupied bandwidth a bandwidth efficiency of 1.92 is achieved increasing to 2.4 b/s as the authorized occupied bandwidth is reduced to 4.0 KHz. But the APCO plan is to employ a variant of 4-QAM, and best case it will fit within the 5.0 KHz emission mask, at 4.8 KHz occupancy it is outside of the 4.0 KHz mask. The solution is, of course, technical.

In the mid 1980's we were advocating the use of 7.5 KHz channel bandwidth for every bandwidth efficient digital cellular communications system. Then, it appeared that given the state of available technology the highest cost effective information rate sustainable in a 6.0 KHz information bandwidth subsumed in a 7.5 KHz channel was approximately 10 kb/s. This scheme was predicated on a bandwidth efficiency of 1.7 b/s/Hz. Our concept at the time ignored the signaling overhead necessary to effect certain system management functions and instead concentrated on very robust half rate error detection and correction (EDAC) coding. At that time, circa 1986 these proposals were met with widespread opposition. Today, in 1993 similar and even more aggressive operational modalities are becoming commonplace.

The question then arises: what happened between 1986 and the present? In a nut shell, the advances have been in the area of digital signal processing technologies. What was allegedly not economically implementable six or seven years ago in monolithic or hybrid technology is now easily implemented through dramatically more powerful DSP's. In fact, with current price versus performance ratios of commercial DSP's, one doubts if current proposal, are pushing the development of the art. Today with DSP technology in the 100's of MIPS range little is difficult or impossible. But for that which pushes the art, we anticipate DSP's operating in the 1000's of MIPS range being available for integration in hand held/portable sets within the next three (3) years.

Today, at the time of this writing in May 1993, anyone may purchase equipment that operates at a gross data rate of 9.6 kb/s in a 12.5 KHz channel vis-a-vis ASTRO which is Motorola's advanced narrow band digital communications (ANDC) implementation. If we assume that the occupied bandwidth is 20 percent of the channel bandwidth, ASTRO type technology has a current bandwidth efficiency of .96 b/s/Hz.

If ANDC is compared to current, 12 kb/s digital voice systems that have been in use since the mid 1970's(which some insist on referring to as analog) which operates in a 25 KHz channel, ANDC's current bandwidth efficiency of .96 b/s/Hz represents almost a 100% improvement as compared to the approximate .6 b/s/Hz bandwidth efficiency of the 12 kb/s systems. This comparison of course neglects the fact that at 9.6 kb/s ANDC provides for embedded signaling that 12 kb/s CVSD systems can not provide in a 25 KHz channel.

Additionally, in the public safety community a standards effort is in process under the Associated Public Safety Officers (APCO) Project 25 umbrella. The APCO 25 process will have as its work product a "standard" for interoperable, advanced narrowband digital public safety communications. Compliant ANDC equipment will initially operate in a 12.5 KHz channel, employing a gross channel data rate of 9.6 kb/s. Voice digitization will be effected at 4.2 kb/s through the use of a vocoder technique referred to as Improved Multi-Band Excitation (IMBE). Embedded encryption, such as DES, and signaling is proposed along with a modest quantify of EDAC resulting in a gross channel rate of 9.6 kb/s. For the initial implementation using compatible Quadrature differential phase shift keying (QDPSK) RF. modulation the system will operate at 12.5 KHz channel spacing. Later, migrating toward 6.25 KHz channel spacing, the compatible architecture is configured to provide a graceful conversion/migration to 6.25 or even 5 KHz channels. This migration may be complicated by the final authorized bandwidth provisions of the refarming NPRM along with the associated technical parameters related to emission shape factor and channel spacing.

The bottom line is that effective use of narrowband channels requires the use of bandwidth efficient techniques that demand more power than their inefficient counterparts. To support the demands of the user population for multi-media information transport, very high bandwidth efficient techniques are mandated.

In addition, we agree with many that see a need for feed forward automatic frequency control techniques and DSP controlled power amplifiers to maintain system integrity.

But most important of all, we believe is the absolute acceptance and use of linear system architecture's. The pioneering work performed by McGeehan and Bateman, from the University of Bristol in the UK over the last decade, scratches but the surface of the potential of linear transmission. It is in this final analysis that linearizing our heretofore corrupted wireless environment will we be able to fully exploit the works of Shannon and maximize the use of our spectrum resource.